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CALCULATION OF THE FREE CARRIER DENSITY PROFILE IN A SEMICONDUC--ETC(U)
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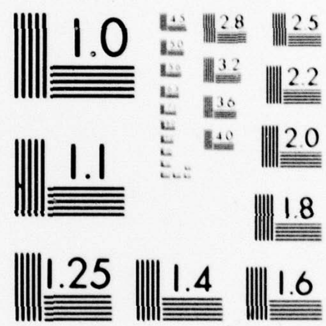
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1.25
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1.6

LEVEL II

(6) CALCULATION OF THE FREE CARRIER DENSITY PROFILE IN A SEMICONDUCTOR NEAR AN OHMIC CONTACT

~~N00014-75-C-0739 Date: 22 June 1979~~

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(11) 22 Jun 79 (10) Amitabh Chandra

In this note, a quantitative attempt is made to answer the question: "To what depth does the equilibrium free carrier density penetrate into a low doped semiconductor from a heavily doped region interfacing it?" The simple answer "A few Debye lengths" can sometimes prove to be inadequate. (12) 7 p.

Let us review, first, the simple 'HI-LO' abrupt n-n homojunction (Fig. 1). For simplicity, assume the LO doping $N_{d\ell}$ to be near-intrinsic, and the HI doping N_{dh} to be non degenerate. The carrier density profile n(x) in the LO region can be obtained by solving Poisson's equation, provided the boundary conditions at x = 0 are known. (15) N00014-75-C-0739

The one dimensional Poisson's equation in either region may be written in a reduced form as

$$\frac{d^2u}{dx^2} = \frac{1}{L_D^2}\left[e^{u-u_{oo}} - 1\right] \tag{1}$$

where

$u = \frac{q\phi}{kT}$ is the reduced potential

$L_D = \sqrt{\frac{\varepsilon kT}{q^2 N_d}}$ is the Debye length in the region

and u_{oo} is the asymptotic value of u at $n = N_d$, in the region.

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The zero of the potential is chosen such that the free carrier concentration may be expressed as

$$n = n_i \, e^u \quad , \tag{2}$$

where n_i is the intrinsic carrier density. A first integration of Eq. (1) gives

$$\left(\frac{du}{dx}\right)^2 = \frac{2}{L_D^2}\left[e^{u-u_{oo}} - 1 - (u-u_{oo})\right] \tag{3}$$

where the condition

$$u = u_{oo} \quad \text{at} \quad \frac{du}{dx} = 0 \tag{4}$$

has been used. Equating the electric fields in the two regions at x = 0 gives upon simplification

$$u(o) = \frac{N_{dh}u_h - N_{d\ell}\,u_\ell}{N_{dh} - N_{d\ell}} - 1 \simeq u_h - 1 \tag{5}$$

since $N_{dh} >>> N_{d\ell}$. The subscripts h and ℓ refer to the HI and the LO regions respectively. Using Eq. (5) in Eqs. (2) and (3) gives

$$n(o) = \frac{N_{dh}}{e} \tag{6}$$

and

$$\left(\frac{du}{dx}\right)_{x=o} = \frac{1}{L_{Dh}}\sqrt{\frac{2}{e}} \tag{7}$$

Having thus obtained the boundary conditions (5-7), Poisson's equation is re-expressed on the LO side as

$$\frac{d^2u}{d\xi^2} = e^{u-u_h} \tag{8}$$

where

$$\xi = \frac{x}{L_{Dh}}$$

and where $N_{d\ell}$ has been neglected in comparison with n.

Integrating Eq. (8), and using Eq. (7) gives

$$\frac{du}{d\xi} = - \sqrt{2e^{(u-u_h)}} \tag{9}$$

A second integration yields

$$\xi = \sqrt{2e^{(u-u_h)}} - \sqrt{2e} \tag{10}$$

where Eq. (5) has been used. Eq. (10) reduces to

$$x(n) = \sqrt{2}\left[L_D(n) - L_D(n(o))\right] \tag{11}$$

where

$$L_D(n) = \sqrt{\frac{\varepsilon kT}{q^2 n}} \tag{12}$$

is the "Debye-like length" corresponding to the carrier density n.

For values of $n \ll n(o)$, $L_D(n(o))$ becomes small in comparison with $L_D(n)$, and $x(n)$ becomes quite insensitive to $n(o)$. Thus, even if the HI region is degenerately doped, the equation

$$x(n) \simeq \sqrt{2}\, L_D(n) \tag{13}$$

is a fairly good approximation for non degenerate values of n. Room temperature values for $x(n)$ at $n = 10^{15} cm^{-3}$

and at 10^{16} cm^{-3} are about 1900 Å and 600 Å respectively.

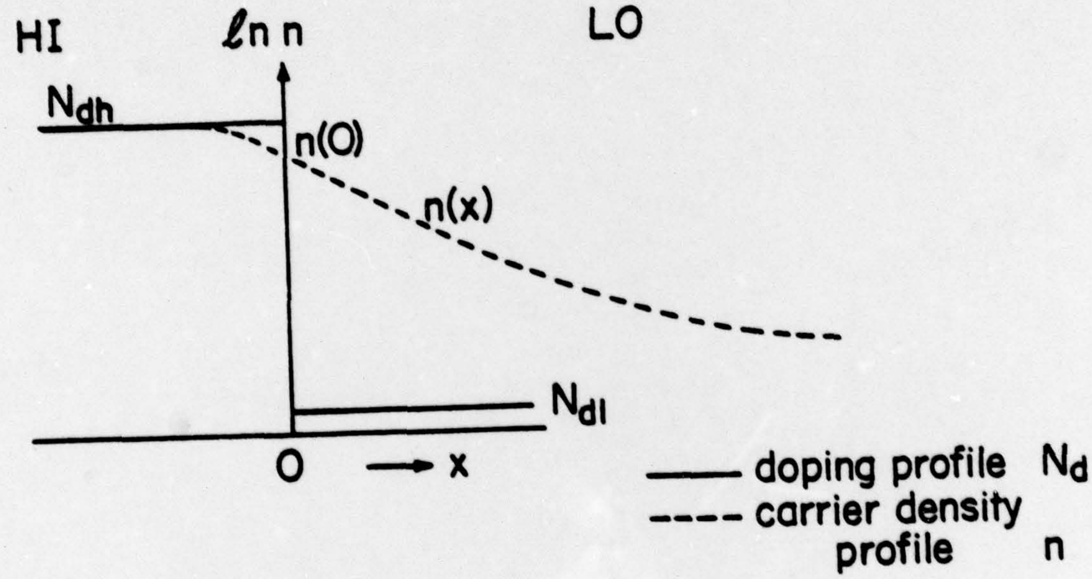
Eq. (13) is valid for $n >> N_{d\ell}$. If n approaches $N_{d\ell}$, then the local space charge density $-q(n-N_{d\ell})$ is overestimated in the above approximation, and $x(n)$ is greater than $\sqrt{2}\ L_D(n)$.

An ohmic contact to a nondegenerate semiconductor may be modeled as a heavily doped region sandwiched between the low doped semiconductor and the metal contact. The above results indicate the extent to which the 'influence' of the ohmic contact can be felt. The point of importance is that the penetration depth of carriers has little to do with the Debye length of the highly doped region, as is a common misconception, but depends on the "Debye-like length" corresponding to the carrier density n being used to define the penetration, as defined in Eq. (12).

The author is indebeted to Professor Charles Lee for valuable discussions.

Figure Captions

Fig. 1. Doping and carrier density profiles across an abrupt HI-LO n-n homojunction.



HI
ℓn n
LO
N_{dh}
n(O)
n(x)
N_{dl}
O
x
doping profile N_d
carrier density profile n

List of Symbols

e	Natural log base
k	Boltzmann constant
L_D	Debye length
L_{Dh}	Debye length on HI side
$L_D(n)$	Debye-like length at n
$L_D(n(o))$	Debye-like length at n(o)
N_d	Net donor density
N_{dh}	Net donor density on HI side
$N_{d\ell}$	Net donor density on LO side
n	Free carrier density
n_i	Intrinsic carrier density
$n(o)$	Free carrier density at $x = o$
q	Electronic charge
T	Temperature
u	Normalized electric potential
u_h	u_{oo} on HI side
u_ℓ	u_{oo} on LO side
u_{oo}	Asymptotic value of u outside space charge region
$u(o)$	u at $x = o$
x	Unit of length normal to junction
ε	(epsilon): Electric permitivity
ϕ	(phi): Electric potential
ξ	(xzi): Normalized unit of length along x direction.